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ABSTRACT

Reducing the fat and/or sugar content in biscuits can be a way to improve their nutritional composition. Seventy-nine consumers of biscuits were recruited to study the impact of these reductions on liking and perception. Four categories of products were selected from a wide range of biscuits available at the French market. Three to six variants of each type of biscuit were produced based on reduced content of sugar, fat or both. Consumers tested the samples under laboratory conditions (6 sessions), recording their liking during initial sessions and crispiness, sweetness and fat perception during latter sessions.

Sugar-reduced biscuits were perceived as less sweet than standard biscuits at low reduction levels, whereas fat-reduced biscuits were perceived as less fatty than standard biscuits at higher reduction levels (except for one biscuit among the three biscuits studied). A reduction in the sugar content had no effect on perception of fat, whereas a reduction in the fat content sometimes induced a reduced sweetness perception. For most of the biscuits studied, the least appreciated variants were those perceived as (1) less sweet, (2) less sweet and less fatty or (3) less sweet and less crispy than standard biscuits. Moreover, the variants only perceived as less fatty were not significantly disliked. These results suggest that from a sensory point of view, it is more acceptable to reduce the fat than the sugar content in biscuits, at least when products are not perceived as being less sweet.

1. Introduction

Sugar and fat are two major ingredients in biscuits. They have crucial structural and textural properties during biscuit dough preparation and baking, providing a typical shape and texture to the final product (Maache-Rezzoug, Bouvier, Allaf, & Patras, 1998; Pareyt & Delcour, 2008; Pareyt et al., 2009; Zoulias, Oreopoulou, & Tzia, 2002). They also play important sensory functions. Sugar is responsible for sweetness, while fat contributes to the texture, mouthfeel, flavour and aroma of food (Drewnowski & Almiron-Roig, 2010; Drewnowski, Shrager, Lipsky, Stellar, & Greenwood, 1989; Mela & Marshall, 1991).

Multiple factors are linked to consumer perceptions of sweetness and fat in biscuits. Sweetness is mainly due to the sugar content (Drewnowski, Nordensten, & Dwyer, 1998; Drewnowski et al., 1989), but it also depends on the fat content and moisture (Abdallah, Chabert, Le Roux, & Louis-Sylvestre, 1998). However, fat perception is more complex than sweetness. It depends on the fat content, the sugar content, texture, moisture, flavour, the nature of the food (liquid or solid) and mouthfeel (Abdallah et al., 1998; Drewnowski & Almiron-Roig, 2010; Drewnowski et al., 1989; Mela, 1990; Mela & Marshall, 1991; Monneuse, Bellisle, & Louis-Sylvestre, 1991).

Overconsumption of fat and sugar is associated with many diseases, such as obesity, high blood cholesterol and coronary heart diseases (Melanson, Astrup, & Donahoo, 2009; World Health Organisation, 2003). Thus, authorities encourage people to reduce fat and sugar consumption in public campaigns such as the National Nutritional Health Program in France (French Ministry of Health, 2006; Hercberg, Chat-Yung, & Chauliac, 2008). Industries are also encouraged to improve the nutritional composition of well-known commercial biscuits.

Reducing the sugar and fat content in biscuits results in structural, textural, sensory and hedonic consequences. Pareyt et al. (2009) described the structural and textural consequences of these reductions on sugar-snap cookies. They reported a modified microstructure, diameter, height and surface cracking pattern of the biscuit.

Sensory consequences of fat and sugar reductions depend on the product and the level of reduction. In biscuits, a 50% butter reduction was not distinguishable, whereas a 25% sugar reduction was perceived as significantly less sweet than a standard biscuit

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(Drewnowski et al., 1998). Nevertheless, Holt, Cobiac, Beaumont-Smith, Easton, and Best (2000) noticed that more consumers had difficulty discriminating different sucrose levels in a solid, high fat biscuit than in water, orange juice or custard.

Liking of biscuits is predicted by the overall flavour intensity, texture, sweetness and fat perception (Abdallah et al., 1998; Drewnowski et al., 1998). Preferences for high fat stimuli were observed even if they are not based on conscious perception of fat content (Abdallah et al., 1998; Drewnowski et al., 1989). Nevertheless, liking seems more related to sweetness than fat perception (Abdallah et al., 1998; Drewnowski et al., 1998). Drewnowski et al. (1998) showed that acceptability ratings for biscuits dropped after a 25% reduction in sugar content, while they were relatively unaffected after a 25% reduction in fat content.

The aim of this study was to assess the impact of fat and sugar reduction on liking, sweetness and fat perception of biscuits. Few recent studies have focused on fat and sugar reduction in biscuits, but most of them dealt with fat- and sugar-reduced biscuits made in the laboratory (Drewnowski et al., 1998; Holt et al., 2000; Pareyt et al., 2009). There were interesting models but not directly comparable to commercial products. In fact, several points differ between laboratory and commercial biscuits. First, recipes of laboratory biscuits are often much more simple than those of commercial biscuits. Indeed, in these studies, biscuits were made with only five (Holt et al., 2000; Pareyt et al., 2009) to nine ingredients (Drewnowski et al., 1998). On the contrary, industrial biscuits contained more than ten ingredients. Second, for technical reasons, some emulsifiers, bulking agents and fibres are sometimes added to reduced variants of commercial products. Indeed, it would not be possible to knead the pastry without these ingredients. Third, subjects consumed laboratory biscuits one or two days after they were produced (Drewnowski et al., 1998; Holt et al., 2000), whereas commercial biscuits are usually consumed when they are in the marketplace, after at least 1 month. Thus, laboratory biscuits have sensory characteristics of homemade biscuits, contrary to commercial biscuits. For all these reasons, we wanted to study if fat and sugar reduction of commercial biscuits would give similar results to laboratory biscuits.

Based on the literature on laboratory biscuits, four hypotheses can be formulated regarding the impact of fat and sugar reduction on sweetness, fat perception and liking of commercial biscuits: (i) Sugar-reduced biscuits are expected to be perceived as less sweet than standard biscuits even at low reduction levels, whereas fat-reduced biscuits are perceived as less fatty than standard biscuits at higher reduction levels; (ii) for a similar level of reduction, sugar-reduced biscuits should be more disliked than fat-reduced biscuits; (iii) it can be assumed that fat- and/or sugar-reduced biscuits should be less liked than standard biscuits as soon as they are perceived as less sweet and to a lesser extent as less sweet and less fatty; (iv) these results should vary according to the categories of biscuits. Thus, several categories of biscuits were studied.

2. Material and methods

2.1. Subjects

French subjects were recruited through mail or circular advertisements. They had to report their level of frequency of their global biscuit consumption on a five-point scale, from "Never" to "More than three times a week". Eighty-six consumers of biscuits were recruited, who consumed biscuits at least once a week.

Finally, seventy-nine subjects took part in the whole study (92% of the initial panel), so we only kept the results for these subjects (64 women and 15 men). Exclusion criteria for participation included those with food allergies and individuals dieting to lose weight. Mean age was 42.5 years old (SD = 5) and mean body mass index (BMI = kg/m^2) was 25.4 (SD = 5.5). The procedure was approved by the local ethical Committee (Comité de Protection des Personnes Est I, Bourgogne). All participants signed an informed consent form and received an indemnity for their participation in the study.

2.2. Products

Four different French commercial dry biscuits were studied: a 'cat's tongue' biscuit (A Biscuit), a 'petit beurre' biscuit (B Biscuit), a chocolate and cereals breakfast biscuit (C Biscuit) and a shortbread biscuit (D Biscuit). A range of three to six variants of each type of biscuit were produced by a French biscuit manufacturer, based on reduced sugar, fat or both. Finally, eighteen variants were developed (Table 1). Differences between these variants were due to changes in fat and/or sugar proportions compared to the original recipe. (F-) and (F- -) were two variants with increasing level of fat reduction. (S-) and (S- -) were two variants with increasing level of sugar reduction. (FS) was a variant both reduced on fat and sugar content. For industrial reasons, the level of emulsifiers, bulking agents or fibres sometimes increased (Table 2). Two other ranges of products (nine variants) made with intense sweeteners were also tested in our experiment. Intense sweeteners were added for technical reasons, but they are known to increase sweetness (Zoulias, Piknis, & Oreopoulou, 2000). Results of these two other ranges of products are not presented in this article.

Biscuits were prepared more than 1 month before the beginning of the experiment in order to recreate the usual consumption conditions of commercial biscuits. For each biscuit, the range of different variants was manufactured on the same day in the same baking conditions to minimise differences in quality between the samples. Biscuits were wrapped in sealed plastic packages labelled with a code letter and sent to the sensory laboratory. Upon arrival, they were stocked at room temperature. Minutes before the beginning of the testing session, biscuits were removed from their packaging and served on identical plastic plates labelled with randomly generated three digit identification codes. New packages were used for each test session to ensure sensory quality consistency.

Pre-tests were conducted in the laboratory to verify that the number of samples chosen was appropriate. Furthermore, at the end of each session of the study, more than 80% of the subjects rated that the quantity consumed was 'just about right'.

2.3. Procedure

Subjects participated in one-hour testing sessions once a week during 6 weeks at 10:30 am, 3 pm or 5:30 pm. However, each subject came each week at the same hour of the day to avoid individual variability between weeks. Subjects were asked to avoid food consumption 2 h before the test to reduce variations between subject hunger levels. All tests were conducted in standardised individual white partitioned booths, lighted with artificial red light to hide possible appearance differences between samples.

For each subject, six testing sessions were necessary to test all the variants of the study, even the two ranges of products not presented in this article. During the first two sessions, biscuits were cut and samples of one or two mouthfuls were served to ensure that the total quantity consumed was not too much. Subjects tasted between twelve and fifteen samples per session and recorded their liking on a nine-point hedonic scale, from "I extremely dislike" to "I extremely like". During the last four sessions, biscuits were cut and samples of three or four mouthfuls were served. Subjects tasted between six and nine samples per session. They ate each sample in three mouthfuls and after each bite, to rate (a) crispiness, (b) sweetness and (c) fat perception on a five-point

Table 1
Nutrient composition of biscuits per 100 g.

Product	Variant	Calories (kJ)	Sugars (g)	Fat (g)	Protein (g)	Carbohydrate (g)	Fibre (g)
A biscuit	(St)	1823.8	43.4	10.6	5.9	77.4	2.0
	(S-)	1764.6	36.3 (−16%)	10.6	5.9	69.8	9.4 (+370%)
	(S- -)	1734.8	32.3 (−26%)	10.7	5.8	66.0	13.1 (+555%)
B biscuit	(St)	1914.3	22.3	15.1	9.0	69.4	3.1
	(F-)	1844.3	22.4	12.5 (−17%)	9.0	69.7	5.3 (+71%)
	(F- -)	1821.3	22.6	11.3 (−25%)	9.1	70.7	5.4 (+74%)
	(S-)	1895.8	19.9 (−11%)	15.1	9.0	67.1	5.3 (+71%)
	(S- -)	1884.5	18.4 (−18%)	15.1	9.0	65.7	6.7 (+116%)
	(FS)	1841.3	20.1 (−9.8%)	12.6 (−16%)	9.2	68.6	5.4 (+74%)
C biscuit	(St)	1297.9	30.3	17.5	7.1	67.1	5.6
	(F-)	1201.6	30.5	14.4 (−18%)	7.4	69.4	5.8 (+4%)
	(F- -)	1109.5	30.5	11.9 (−32%)	7.7	71.4	5.9 (+5%)
	(S-)	1214.2	25.3 (−17%)	17.3	7.7	66.2	5.9 (+5%)
	(S- -)	1193.2	21.6 (−29%)	18.1	8.1	64.5	6.2 (+11%)
	(FS)	1046.7	23.1 (−24%)	13.3 (−24%)	8.5	68.4	6.6 (+18%)
D biscuit	(St)	2054.0	25.0	21.3	6.5	67.0	2.0
	(F-)	1991.0	25.0	18.0 (−15%)	7.0	70.0	2.0
	(F- -)	1932.0	25.0	14.8 (−31%)	7.5	73.0	2.0

(S-) and (S- -) are two variants with increasing level of sugar reduction.
(F-) and (F- -) are two variants with increasing level of fat reduction.
(FS) is a variant reduced in both fat and sugar content.
Percentages of fat and/or sugar reduction and of fibre addition are indicated in parentheses.

Table 2
Modification of ingredient proportions.

Biscuit	Ingredient	(F-) %	(F- -) %	(S-) %	(S- -) %	(FS) %
A biscuit	Polydextrose			+6.70	+10.50	
B biscuit	Flour		+2.00			+3.00
	Polydextrose	+2.20	+2.20	+2.20	+3.60	+2.20
	Lecithin	+0.50	+0.60			+0.50
C biscuit	Flour	+2.00	+4.00	+4.00	+6.00	+8.00
	Emulsifier		+0.17		+0.10	+0.18
	Lecithin	+0.03	+0.02			+0.04
	Cocoa powder		+0.05		+0.16	+0.49
	Rolled oats		+0.11		+0.33	+0.48

For biscuit D, no ingredient was modified. Grey boxes refer to non-manufactured variants.

intensity scale, from "not at all" to "extremely" crispy, sweet and fatty.

Subjects were asked to consume samples entirely, swallow and rinse their mouth with mineral water between tasting successive samples. During each session, several ranges of biscuit were presented one after the other. For each range of biscuits, variants were presented in a monadic way, during the same session. The presentation order of the different products and the presentation of each variant followed Williams Latin squares balanced for order and first-order carry-over effects (MacFie, Bratchell, Greenhoff, & Vallis, 1989). However, each subject had the same presentation order of the different variants for both liking and perception tests to avoid individual variability.

2.4. Data analysis

Statistical analyses were conducted using the SAS System for Windows version 9.1 (SAS Institute, Inc., Cary, NC, USA). The significance level was set at $p < 0.05$.

For each product, two-way analyses of variance were performed with subjects and variants as factors and liking, crispiness, sweetness and fat perception as variables. In these models, contrast tests were performed to compare each reduced variant with the standard biscuit. In addition, the difference between the mean of each reduced variant and the standard biscuit was calculated. Crispiness, sweetness and fat perception scales ranged from 1 to 5. The liking scale was from 1 to 9, with differences between −8 and 8.

3. Results

The impact of fat and sugar reduction on sensory perception and liking of biscuits was studied. Table 3 summarises the results, and they are presented in the text by reduction (fat, sugar or both) and by measure (crispiness, sweetness, fat perception and liking).

3.1. Effect of fat and/or sugar reduction on perception

3.1.1. Effect of fat (resp. sugar) reduction on fat (resp. sweetness) perception

For B and C Biscuits, the most fat-reduced variant (F- -) was perceived as significantly less fatty than the standard biscuit (St), while the intermediate fat-reduced variant (F-) was not perceived as less fatty than the (St). Biscuits D (F-) and (F- -) were both perceived as significantly less fatty than the (St). For B and C Biscuits, (FS) was not perceived as significantly less fatty.

For each biscuit, the three sugar-reduced variants (S-), (S- -) and (FS) were perceived as significantly less sweet than the (St). Biscuit B (S- -) was the one exception, but it tended to be significant.

Table 3
Impact of fat and/or sugar reduction on crispiness, sweetness, fat perception and liking (n = 79).

		Variant effect		Mean	Fat reduction		Sugar reduction		Fat and sugar reduction
Measure	Biscuit	*F*-value	*p*-value	(St)	(F-)	(F- -)	(S-)	(S- -)	(FS)
Fat perception	A	1.45	0.2381	2.18			ns	ns	
	B	2.81	0.0165	2.18	ns	−0.23*	ns	ns	ns
	C	4.53	0.0005	2.16	ns	−0.29**	ns	ns	ns
	D	30.79	<0.0001	2.87	−0.35**	−0.72***			
Sweetness	A	6.99	0.0012	3.53			−0.24*	−0.43***	
	B	3.36	0.0055	2.75	$-0.19^{0.07}$	−0.36***	−0.37***	$-0.21^{0.06}$	−0.29**
	C	25.42	<0.0001	2.99	−0.24*	ns	−0.60***	−0.76***	−0.96***
	D	8.57	0.0003	2.91	ns	−0.42***			
Crispiness	A	1.58	0.2084	4.32			ns	ns	
	B	1.51	0.1866	3.99	ns	ns	ns	$-0.23^{0.07}$	ns
	C	48.09	<0.0001	3.84	ns	ns	−0.60***	−1.40***	−1.59***
	D	0.46	0.6329	3.57	ns	ns			
Liking	A	19.50	<0.0001	6.82			−0.43*	−1.11***	
	B	3.58	0.0035	6.54	ns	−0.78***	ns	ns	−0.48*
	C	19.17	<0.0001	6.05	−0.78***	$-0.39^{0.06}$	−0.73***	−1.14***	−1.83***
	D	9.18	0.0002	6.30	ns	−0.81***			

Contrast tests results of the two-way anova model (Subject + Variant) on liking/perception for each product. Results show the *F*-value and the *p*-value of the variant effect, the mean of the standard variant and the difference between the mean of each reduced variant and of the standard one (St).
*$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$ refer to the level of the significance of the difference between the reduced variant and the standard one. When $0.05 < p < 0.08$, the value of the *p*-value is given in exponent position. 'ns' refers to a non significant difference. Grey boxes refer to non-manufactured variants.

3.1.2. Effect of fat (resp. sugar) reduction on sweetness (resp. fat) perception

Regardless of the type of biscuit, neither of sugar-reduced variants (S-) and (S- -) were perceived as significantly less fatty than the (St).

The fat-reduced variant (F-) was perceived as less sweet than the (St) for C Biscuits and tended to be perceived as less sweet for B Biscuits. Moreover, (F- -) was perceived as less sweet than the (St) for B and D Biscuits. For B and C Biscuits, the fat- and sugar-reduced variant (FS) was perceived as significantly less sweet but not less fatty than the (St).

3.1.3. Effect of fat or sugar reduction on crispiness

The results showed no effect of fat reduction on crispiness. Furthermore, (S-), (S- -) and (FS) were not perceived as significantly different from the (St) for A and B Biscuits, except for Biscuit B (S- -) which tended to be less crispy than the (St). For C Biscuits, (S-), (S- -) and (FS) were perceived as significantly less crispy than the (St).

3.2. Effect of fat and/or sugar reduction on liking

Concerning fat reduction, (F-) was significantly less liked than the (St) for C Biscuits but not for B and D Biscuits. (F- -) was significantly less liked than the (St) for B and D Biscuits and tended to be less liked for C Biscuit. Concerning sugar reduction, (S-) and (S- -) were significantly less liked than the (St) for A and C Biscuits but not for B Biscuit. For sugar and fat reductions, (FS) was significantly less liked for the both biscuits studied.

By comparing perception and liking scores, it appears that the less liked variants were mainly those perceived either as less sweet [i.e., Biscuits A (S-) and (S- -); Biscuit B (FS); Biscuit C (F-)], less sweet and less fatty [i.e., Biscuit B (F- -); Biscuit D (F- -)] or as less sweet and less crispy [i.e., Biscuit C (S-), (S- -) and (FS)] than the (St) variants.

In contrast, variants only perceived as less fatty [i.e., Biscuit C (F- -) and Biscuit D (F-)] were not significantly disliked, even if they tended to be for Biscuit C (F- -). Biscuit B (S-) was still liked even if it was perceived as less sweet than the (St). Besides, for each type of biscuit, no fat- or sugar-reduced variants were more liked than standard one.

4. Discussion

4.1. Effect of fat and/or sugar reduction on perception

According to our hypothesis i, sugar-reduced biscuits were perceived as less sweet than standard biscuits at low reduction levels, whereas fat-reduced biscuits were perceived as less fatty than standard biscuits at higher reduction levels. These results are similar to those previously observed in the study of Drewnowski et al. (1998) on six types of laboratory biscuits with reduced sugar and/or fat content.

This could be explained by the fact that fat perception is known to be more complex to perceive and to characterise than sweetness (Drewnowski & Almiron-Roig, 2010; Mela, 1990; Mela & Marshall, 1991). Moreover, it may be due to the semantic term that we selected to assess fat perception. During the study, we asked subjects how fatty were the biscuits, but other descriptors could have induced other results. Drewnowski et al. (1989) described the difficulty in choosing suitable attribute scales for the assessment of fat content in different foods, summarising the descriptors that exist to describe the lipid mouthfeel: smooth, oily, greasy, waxy, melting, slimy, creamy, thick, heavy and syrupy. In their study on six types of fat- and/or sugar-reduced biscuits, Drewnowski et al. (1998) used the term buttery. However, in the present study, we thought this term would be biased toward A and C Biscuits so we chose the term fatty, which is better adapted to all the biscuits.

Nevertheless, there is one exception: one biscuit was perceived as less fatty than the standard biscuit from the first level of fat reduction. This could be related to the fact that the standard variant of this biscuit initially contained more fat than the other biscuits. This finding indicates that the total quantity of fat content removed is higher. Moreover, contrary to the other biscuits, this is a buttery biscuit; thus, the fat content is perhaps easier to perceive due to the buttery flavour. This also can be due to the fact

that it was the only biscuit with no extra ingredient in the fat-reduced variants.

Crispiness was the first perception scale given to subjects, so they could familiarise themselves with this scale before rating sweetness and fat perception. It also permitted subjects to focus on other perceptions besides sweetness and fat. Furthermore, we wanted to know if the reductions in sugar and/or fat content would change the textural perception of biscuits. Previous studies showed that sugar and fat reduction has important structural and textural consequences on biscuits (Maache-Rezzoug et al., 1998; Pareyt et al., 2009). Our results revealed that fat reduction did not affect crispiness in the biscuits studied. For sugar reduction, it only had an effect on one biscuit for which sugar-reduced variants were perceived as less crispy than the standard biscuit.

Drewnowski et al. (1998) also observed that there was no systematic link between fat reduction and texture-related attributes; rather, it was dependent on the type of biscuit. This could be due to three reasons. First, the structural and textural consequences of sugar or fat reduction described by Pareyt et al. (2009) and Maache-Rezzoug et al. (1998) were only measured by instruments. Perhaps these modifications are not perceptible by humans, especially when products are tested by consumers and not by an expert sensory panel. Second, the results may also be related to the choice of the descriptor of texture. Crispiness was chosen because all of the biscuits in the present study were crispy dry biscuits. However, for each type of biscuit, there is no difference concerning crispiness but perhaps we should have observed other textural differences if we had studied other textural descriptors. Third, for B and C Biscuits, the crispiness stability of the (F-) and (F- -) variants, compared to the standard biscuits, could also be due to the addition of some emulsifiers, bulking agents or fibres (Table 2). Indeed, in our study, biscuits were manufactured by biscuit producers, contrary to the study of Drewnowski et al. (1998) in which biscuits were prepared in the laboratory without any additional ingredient. This methodological difference could explain why they observed that the effect of texture-related attributes depended on products, whereas in our study, all of the fat-reduced variants showed no effect on crispiness. Thus, this shows that industry is able to mask the reductions, at least to some extent.

We observed that sugar reduction had no effect on fat perception, whereas fat reduction sometimes induced a decrease of sweetness response by the participant. A similar effect has been reported for biscuits (Abdallah et al., 1998) and dairy products (Bouhlal, 2011; Tuorila, Sommardahl, Hyvönen, Leporanta, & Merimaa, 1993). To explain this interaction, three explanations can be suggested. First, Abdallah et al. (1998) suggest that fat provides retronasal olfactory input in the form of fat-soluble molecules (aroma) that enhance flavour intensity, which is very closely related to pleasantness ratings. This modification of pleasantness could increase salivary secretion and the solubility of sweet compounds in the mouth and therefore lead to a more intense sweet perception. Second, this could be related to a synergy between sugar and fat, as in dairy products, where fat was shown to enhance perceived sweetness (Bouhlal, 2011; Tuorila et al., 1993). Third, consumers might associate the perceived global sensory difference to sweetness instead of fat perception because fat perception is more difficult to identify (as was discussed earlier).

4.2. Effect of fat and/or sugar reduction on liking

Our results revealed that fat-reduced biscuits are less liked than standard biscuits, but for two of products among three products, it is only significant for the higher level of fat reduction. This finding confirms the results observed by Drewnowski et al. (1998) on six types of fat-reduced biscuits. They observed that reducing the fat content by 25% had no impact on overall product acceptability, which declined only when fat was reduced by 50%. In their study, the two levels of fat reduction were higher than in our study, where the first level of reduction is approximately −15% of fat content, and the second level of reduction is between −25% and −32% of fat content depending on the biscuits. For the C Biscuit, surprisingly, we observed that (F-) was significantly less liked than the standard biscuit, compared to (F- -), which tended to be less liked. This could be due to the particularities of this product that will be discussed in the next chapter.

For two of the three products studied, sugar-reduced variants are less liked than standard biscuits for both levels of sugar reduction. These results are consistent with the results of Drewnowski et al. (1998), on six types of biscuits initially containing sugar contents similar to ours. The authors observed that reducing the biscuit sugar content by 25% had an immediate and adverse impact on overall liking ratings. In our study, the first levels of sugar reduction were lower than 25%; thus, we observed that sugar-reduced biscuits are even less liked than standard biscuits by −16% or −17% of sugar content. However, for the B Biscuit, both (S-) and (S- -) were not significantly less liked than the standard biscuit. This result can be explained by the fact that this biscuit initially contained less sugar than the other biscuits and that these variants were less reduced in sugar content. Overall, the most reduced variant was only reduced by −18% of sugar content.

According to our hypothesis ii, reduced variants were less liked than standard biscuits, and for a similar level of reduction, sugar-reduced biscuits were more disliked than fat-reduced biscuits. By comparing the results of the perception and of the liking scores, the less liked variants were mainly those only perceived as less sweet, and, to a lesser extent, less sweet and less fatty or less crispy than the standard biscuits. In contrast, variants only perceived as less fatty are not significantly less liked, even if it tended to be for one variant. These results confirm our hypothesis iii, according to which sweetness is the key sensory attribute that determines liking, which is in agreement with other studies on fat- and/or sugar-reduced biscuits (Drewnowski et al., 1998) or chocolate puddings (Geiselman et al., 1998).

4.3. Product considerations

We studied several types of biscuits assuming that the results would depend on biscuits (hypothesis iiii), as was observed in other studies on sweetness and fat perception and liking in biscuits (Abdallah et al., 1998; Drewnowski et al., 1998). This was verified for each type of measurement (crispiness, sweetness, fat perception and liking).

Three main reasons can explain why we observed such differences between the types of biscuits. The first one is that the different biscuits did not initially contain the same levels of sugar and fat, and the levels of reduction obtained were not exactly the same between biscuits.

The second one is that the four types of biscuits differ in their ingredients, aroma and texture. Thus, as was discussed earlier, D Biscuit was a buttery biscuit, which could have had a specific effect on fat perception. In addition, distinct results were obtained for C Biscuits in comparison to the other studied biscuits, which may be because it is the only chocolate biscuit of our study, and the only biscuit without egg. Sugar and fat reduction should have reduced chocolate flavour intensity, which should have had an effect on liking, as has been previously observed in the study of Geiselman et al. (1998) on fat- and sugar-reduced chocolate puddings. The four types of biscuits were well-known by French consumers, but the C Biscuit was unique because it was a biscuit usually consumed during breakfast, for nutritional reasons, whereas the other biscuits were traditional French biscuits, usually consumed for pleasure.

The third reason is that some fibres have been added to half products. Some studies on fibre-enriched muffins showed that an addition of fibres can have a negative effect on liking (Baixauli, Salvador, Hough, & Fiszman, 2008; Mialon, Clark, Leppard, & Cox, 2002). In our study, addition of fibres is very important in A and B biscuits, whereas there is almost no addition of fibres in C and D biscuits (Table 1). Thus, this can be another interpretation to explain why some reduced variants of A and B Biscuits are disliked. However, this cannot be the only explanation since for sugar reduction, Biscuits A (S-) and (S- -) are less liked than the (St) but Biscuits B (S-) and (S- -) are not.

Biscuits were cut in samples of one or two mouthfuls (liking sessions) and three or four mouthfuls (perception sessions). Biscuits were cut in order not to have too much quantity to eat in the same session. This was done in order not to add other sessions, because it is hard to keep subjects during a lot of sessions. The size of pieces may have affected the scores. However, this was not a real problem in our case, because our aim was to compare the liking or perception scores of each variant in relation to the standard variant, and all the variants of the same type of biscuit were cut in the same way.

The energy density of foods is largely determined by their water and fat contents (Drewnowski, 1998). In our study, fat- and/or sugar-reduced biscuits did not exceed a −5% energy density reduction, except for C Biscuits in which the percentages of reduction of energy density ranged from −6% for the (S-) to −19% for the (FS) variant (Table 1). This moderate impact on energy density emphasises that efforts to reduce sugar and fat content made by the food industry are limited. Thus, these efforts must be followed by numerous industries and on several different products to succeed in reducing the mean energy density of the diet of the entire population.

4.4. Strengths and limitations

The biscuits of the present study were manufactured by biscuit producers, contrary to the laboratory manufactured biscuits in Drewnowski et al. (1998). The impact of fat and sugar reduction on famous French biscuits manufactured in industrial conditions (wrapped in sealed plastic packages and consumed after several weeks, similar to consumption conditions of commercial biscuits) could be assessed in this study. Furthermore, for industrial reasons, the level of emulsifiers, bulking agents or fibres increased so this is difficult to distinguish the impact of these modifications from the impact of fat or sugar reduction.

For practical reasons, some subjects came at 10 am or 3 pm ($n = 22$) whereas all the others came at 5:30 pm ($n = 57$). We wanted to verify that it did not have effect on measures, so we performed a split-plot analysis. No effect was observed so we kept the results of the whole group.

We hypothesised that a reduction of the sugar and fat content in several types of biscuits would have different impacts on sensory perception and liking (hypothesis iiii). Four types of biscuits were chosen among the wide range of French commercial dry biscuits. However, for technical reasons, the level of reduction of the different biscuits was dependent on the biscuits, and some biscuits were only reduced for one sensation (sugar or fat content). Furthermore, as discussed earlier, modifications of ingredients depended on biscuits. Results emphasised that the types of biscuits reduced for sugar and/or fat content showed similarities but also distinct results. These results indicate that generalisation of these results for all types of commercial biscuits would be difficult and would be even more difficult to extrapolate to other categories of products. However, these results obtained on four ranges of biscuits are encouraging, and this could encourage other industrials to try to reduce the fat and sugar content in their products.

5. Conclusions

Our results with fat- and sugar-reduced biscuits manufactured in industrial conditions are in agreement with results from biscuits made in laboratory conditions.

The results depended on the type of biscuit, but some points can be emphasised. A reduction in fat content is more difficult to perceive than a reduction in sugar content, and this reduction sometimes induces a reduction of sweetness. Fat- or sugar-reduced dry biscuits are less liked than the standard biscuits only when they are perceived as less sweet. These results suggest that from a sensory point of view, it is easier to reduce the fat than the sugar content, at least when products are not perceived as less sweet.

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